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VISUAL-VESTIBULAR AND POSTURAL ANALYSIS OF MOTION SICKNESS, PANIC, AND ACROPHOBIA

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SUMMARY

Background: Visual-vestibular and postural interactions can act as cues that trigger motion sickness and can also have a role in some anxiety disorders. We explore a method to detect individual sensitivity to visual-vestibular unusual patterns, which can signal a vulnerability to develop motion sickness and possibly anxiety disorders such as a fear of heights and panic.

Material/ Methods: 65 undergraduate students were recruited for the purposes of this study as voluntary participants (44 females); average age 21.65 years (SD=2.84) with normal or corrected to normal vision, without vestibular or postural deficiencies. Panic was assessed with the Albany Panic and Phobia Questionnaire, Motion Sickness with the Motion Sickness Susceptibility Questionnaire and Acrophobia was assessed by means of the Acrophobia Questionnaire. The Sharpened Romberg Test was used to test participant's postural balance. The Rod and Frame Test (RFT) measures the participant's ability to align a rod to the vertical within a titled frame providing a measure of error in the perception of verticality by degrees. This test was changed to measure the error offered when a participant's head was tilted, and to trace the error caused by manipulating the vestibular system input.

Results: The main findings show only motion sickness to be correlated with significant errors while performing a visual-vestibular challenging situation, and fear of heights is the only anxiety disorder connected with postural stability, although all disorders (fear of heights, panic and motion sickness) are correlated between each other in the self-report questionnaires.

Conclusions: All disorders are correlated to each other in the surveys, and might have some common visual-vestibular origin, in theory. The rod and frame test was exclusively correlated with motion sickness whereas the postural stability test only displayed sensibility to acrophobia. Panic disorder was correlated to neither the RFT nor the Romberg. Although this method was initially employed to increase sensibility in order to detect anxiety disorders, it ended up showing its value in the detection of motion sickness.

Key words: motion sickness, fear of heights, panic disorder, visual-vestibular interaction, rod and frame test, Romberg test

INTRODUCTION

Several authors have conjectured that anxiety disorders, such as panic and acrophobia may have visual-vestibular and/or postural aetiological factors, similarly to motion sickness (see Coelho & Balaban, 2014 for a review; Viaud-Delmon, Berthoz, & Jouvent, 2002; Viaud-Delmon, Warusfel, Seguelas, Rio, & Jouvent, 2006; Riccio and Stoffregen, 1991). In fact, some authors (e.g., Stoffregen and Smart, 1998) suggest that vestibular-ocular conflicts only cause motion sickness if there is postural instability. Consistent with this hypothesis, participants with symptoms of panic often become destabilized under conflicting sensory conditions (Jacob, Furman, Durrant, & Turner, 1996, 1997; Yardley, Luxon, Lear, Britton, & Bird, 1994). This postural instability associated with anxiety was mainly explored by Jacob and colleagues and based on reported observations that some patients with balance disorders exhibit particular avoidance profiles (e.g., Jacob et al., 1996; Jacob, Redfern, & Furman, 1995, 2009). For example, Jacob and colleagues (1996) found vestibular abnormalities to be common in patients with panic disorder and agoraphobia. They also found vestibular dysfunction to be associated with the frequency of vestibular symptoms and discomfort in particular situations. Jacob and Colleagues (1996) were able to observe commonalities between several cases referred to in the subject literature, namely: street neurosis, the supermarket syndrome, space phobia, and motorist's vestibular disorientation syndrome (e.g., Levy & O'Leary, 1947; Marks, 1981; Marks & Bebbington, 1976; McCabe, 1975; Page & Gresty, 1985; Rudge & Chambers, 1982). The supermarket syndrome occurs in Ménière's disease and involves an intolerance to looking back and forth along aisles and up and down shelves (McCabe, 1975) or the inability to walk between the shelves in a supermarket (Rudge & Chambers, 1982). The motorist's vestibular disorientation syndrome was documented by Page and Gresty (1985) after observing a group of patients with minimal symptoms of a neuro-otological disease; these patients became disoriented while driving on open roads or when going over the crests of hills. The hallmark of space phobia is an intense fear evoked by spatial cues when standing without support close by or while driving a car. These syndromes report situations with inadequate visual or proprioceptive balance cues, which for patients with vestibular deficits, who are visually or proprioceptively dependent, may cause symptoms of imbalance, discomfort, anxiety, or phobic avoidance (Wackym & Schumacher-Monfre, 2006). It is notable that situations that elicit space and motion discomfort are also related to conditions that have an enhanced potential to create visual-vestibular conflicts.

A parallel between acrophobia (fear of heights) and a visual-vestibular trigger has also been established by other studies, which found height vertigo to be associated with the destabilization of posture caused by a lack of visual parallax cues (Bles, Kapteyn, Brandt, & Arnold, 1980; Brandt, Arnold, Bles, & Kapteyn, 1980, see also Brandt & Huppert, 2014). This suggests a visual-vestibular conflict, similar to the ones that can cause MS. In line with this finding, Coelho and Wallis

(2010) found that people with poor postural stability in the absence of visual cues, and more dependent of the visual field to keep postural stability, were more disposed to show a fear of heights. Besides (Aslan, Songu & Aslan, 2012) found was an incidence of 41% acrophobia among 34 MS patients (32 female). More recently, Willey and Jackson (2014), using the Rod and Frame Test (Witkin & Asch, 1948), tested participants with a fear of heights. This test allows the measuring of the subjective visual vertical. In the Rod and Frame Test (RFT), participants are asked to align a bar (rod) inside a squared frame, until it reaches an upright position. The rod's subjective visual vertical (SVV) is usually influenced in the direction of the frame tilt; when the outer frame is tilted, the participant produces errors in the alignment of the rod that can be measured by the angle of deviation from the true vertical. The resulting error provides a quantitative measure indicative of what is usually called, in the literature of the RFT task, the participant's visual field dependence. Participants with significant errors are often called visual field dependent, and those with small errors or who can set a line or rod accurately to an objectively vertical position in the presence of a tilted surrounding frame, are often called field-independent. Willey and Jackson (2014) found that participants with a fear of heights relied more on visual information, compared to controls, but this difference did not reach the significance threshold. Overall, these findings contribute to evidence suggesting that a visual-vestibular component could also be present in acrophobia.

Motion sickness links to visual-vestibular components have also been documented, with some studies using the angular error in RFT as the dependent measure – but the findings are contradictory. Barrett and Thornton (1968) and Kennedy (1975) revealed that visual field dependent individuals, measured with the RFT, were less susceptible to feeling motion sickness, while Long, Ambler, and Guedry (1975) found the opposite. Also using the RFT, Barrett and Thornton (1968) reported that field-independent subjects had a significantly higher incidence of sickness in the automobile simulator than did field-dependent subjects. This outcome was seen as paradoxical by Long et al. (1975. However, this result might be in agreement with individual differences in sensitivity to multimodal, visual-vestibular integration. But other interpretations can be found: Barrett and Thornton (1968) suggested that field-independent subjects perform well in the RFT situation because of a predominant sensitivity to body (kinesthetic and vestibular) cues, and that their higher incidence of sickness with the simulator was caused by the relatively greater conflict they experienced between these static body cues and the dynamic visual cues of the moving display. Field-dependent subjects were hypothesized to be relatively less „body sensitive" and therefore characteristically less aware of the visual-vestibular conflict posed by a fixed based simulator setting and thus less subject to illness. This view was later modified by Barrett, Thornton, and Cabe (1970), who found that for milder cue-conflict situations, field dependent persons reported more disturbance than field-independent persons. It is interesting to note that, regarding the etiology of motion sickness, in circumstances in which body motion is involved, a „conflict theory" has also frequently been employed (cf. Money, 1970 see Bertolini & Straumann, 2016 for a review). It will be of theoretical and applied value to measure participants' subjective vertical while manipulating the vestibular input (head tilt) to explore their susceptibility to motion sickness and anxiety disorders comparatively. Following previous findings it has been shown that anxiety disorders share common clinical features with balance disorders, panic attacks, and vertigo (see also Lepicard, Venault, Negroni, Perez-Diaz, Joubert, Nosten-Bertrand, Berthoz & Chapouthier, 2003 for animal studies). We now aimed to directly compare, in the same individual, the magnitude of the angular error in the RFT task, with scores for motion sickness, postural control, fear of heights, and panic disorder, as measured by standard clinical measures.

METHODS

Participants

65 undergraduate students were recruited as voluntary participants for the study (44 females) with an average age of 21.65 years (SD=2.84), and with normal or corrected to normal vision, without vestibular or postural deficiencies. The study was approved by the institutional review board of the University of Minho, Portugal, and all participants provided written informed consent according to the Declaration of Helsinki Convention on Human Rights and Biomedicine, the Council for International Organizations of Medical Sciences and the Guide to Good Clinical Practices.

Materials

Motion Sickness was assessed with the Motion Sickness Susceptibility Questionnaire (Golding, 1998), acrophobia was assessed with the Acrophobia Questionnaire (Cohen, 1977) and Panic was assessed with the Albany Panic and Phobia Questionnaire (Rapee, Craske, & Barlow, 1994). The Acrophobia Questionnaire describes 20 situations frequently mentioned by people with acrophobia as anxiety provoking (e.g., standing next to an open window on an elevated floor). The Sharpened Romberg Test (Fregly & Graybiel, 1968) was used to test participant's postural balance. For the purpose of our study, we chose to use the most sensitive version of the test (barefoot with arms crossed) because participants reported no apparent dysfunction of the proprioceptive, cerebellar, or vestibular pathways. Participants were instructed to stand quietly with arms crossed in front of their chest, first for a single trial (each foot in front), and afterwards for up to six trials (3 for each foot). The participant was asked to maintain the posture for 120 sec, without making a visible step to the side. The final score in the task was the average of the six trials. Participants stood barefoot with eyes closed and arms crossed, with the tip of one foot close to the heel of the other (tandem position), such that both feet occupied a lateral area not greater than the width of one foot.

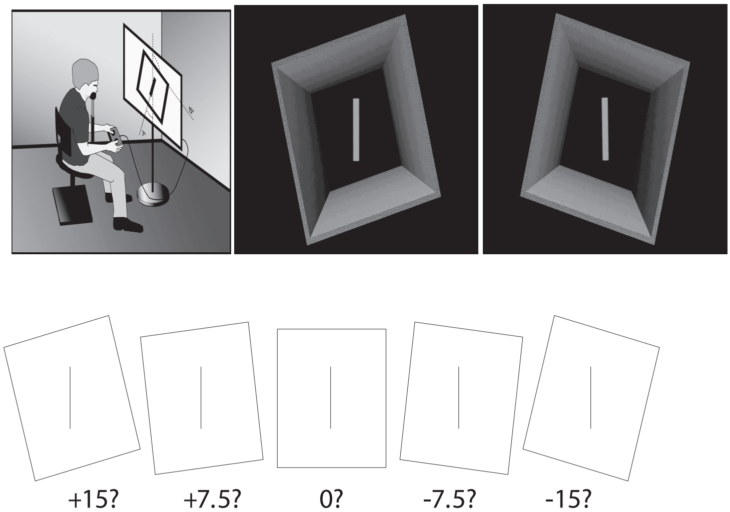

Fig. 1. (above) Apparatus used to test participant (left) and a screenshot of actual stimuli. (below) The frame was presented at +15°, +7.5°, 0°, -7.5°, 15° of tilt, and the participant's head was either straight or tilted 90° to the left; the bar inside each square is the vertical position. Positive angles correspond to counter-clockwise rotations (i.e., to the left of the true vertical)

The Rod and Frame Test (Witkin & Asch, 1948) provides a measure of error in the perception of verticality; the participant is asked to orient a rod, so it appears to be vertical. The RFT measures a participant's ability to make the alignment when the rod is within a tilted frame. In our implementation of the RFT, we used a 5 (Frame Orientation) x 2 (Head Orientation) within-subjects design: Frame Orientation was presented in five different adjustments (+15°, +7.5°, 0°, -7.5°, -15°); and the participant's Head Orientation was either straight or tilted 90° to the left during the task. Counter-clockwise rotations correspond to positive angles, i.e., for this study, a positive angle is a rotation to the left from the correct vertical line. The within-subjects design consisted of 10 trials per frame orientation, thus 50 trials for Head Straight, and 50 trials for Head Tilted 90° to the Left. The frame tilt of 15^{o} was used due to the finding that this value is where the RFT effect has been found to be maximal, following the procedures outlined by Zoccolotti, Antonucci & Spinelli (1993). Head Orientation was blocked, and Frame Orientation was randomized, and participants had 3s per trial to perform the task.

Procedure

The rod and frame scene was presented on a computer monitor while participants were seated 45 cm from the monitor (see Figure 1); custom-made software, based on the Ogre3D graphics engine library, Ogre 3D (2015, December 22), was used to render, in perspective projection, a virtual rod, and frame on the screen. The frame was rendered as a square box without the front and back sides, and the rod was presented as a cylinder centered inside the square box, i.e., the participant could see inside the squared box in depth, and the cylindrical rod was inside the box. The side of the box closest to the viewer subtended 28.6º x 28.6º of the visual angle, and the side of the box farthest from the viewer subtended 16.1º x 16.1º of the visual angle. Participants could rotate the rod clockwise and counterclockwise by clicking and moving the computer mouse right and left respectively. At the end of each trial, the software recorded the orientation of the rod. The update rate of the rendering was 50 Hz, and the image resolution was set at 1280 x 1024 pixels. The test was conducted in the dark to remove extraneous visual cues.

The rod starting point was not presented always in a horizontal orientation to avoid the possibility that participants could memorize the gesture that would place the rod in the apparent vertical, instead of being guided mainly by vision. As such, the rod was initially presented either approximately horizontal or slightly sloped to either left or right of the horizontal line. The initial orientation was randomly sampled from the following set of angles: ±45º, ±55º, ±65º, ±75º and ±85º as the rod presentation can impact results as well (Toupet, Van Nechel & Grayeli, 2015).

RESULTS

The primary analysis consists of two parts: (1) modeling the participant's mean angular error in the RFT task and (2) a correlation analysis between RFT, performance in the Sharpened Romberg Test, and the questionnaire-based clinical measures for motion sickness, acrophobia, social phobia, and agoraphobia.

The angular error in the RFT task was analyzed using circular statistics (a branch of Statistics concerned with data that can be represented as points on the unit circle, as opposed to the real line). Computation of sample estimates and the statistical inference was conducted with the R package 'circular' (Agostinelly & Lund, 2013) and CircStat, the Matlab Circular Statistics Toolbox (Berens, 2009); we followed the methodology of Pewsey, Neuhäuser, & Ruxton (2013). Per participant and trial, we computed the angle between the rod's final orientation (the subjective visual vertical) and the correct vertical. Angular errors above 10º were excluded; this removed 78 data points (1.2% of the total). After, we fitted the RFT angular error data with a 5 (Frame Orientation) x 2 (Head Orientation) ANOVA using CircStat. The key finding is evident in Figure 2 that shows, for each cell of the 5x2 design, the participant's angular error distribution and the sample mean angular error.

When the participant's head was straight, the sample mean angular error is near zero, irrespective of the frame orientation (see Table 1 for the sample estimate and respective confidence interval). When the participant's head was tilted 90 degrees to the left, and the frame was also tilted to the left, the sample mean angular error was clearly non-zero and in the direction of the frame tilt. In sum, we found, that when head and frame are tilted to the same side (taking participants' VOF into account) participants show an increased error towards that side, consistent with the previous classic studies (e.g., Witkin, Herman & Asch 1948).

This was confirmed by the ANOVA model that yielded a significant main effect of Frame Orientation, $F(4, 640) = 8.25$, $p < .001$, a significant main effect of Head Orientation, $F(1, 640) = 11.48$, $p < .001$, and a significant two-way interaction, $F(4, 640) = 4.97$, $p < .001$.

The analysis of the participant's mean angular error in the RFT shows we have induced a measurable error in the group mean rod alignment, compared with the true vertical, in two conditions: frame orientation at +15° and +7.5°, and while the head was tilted to the left. Our main question of interest was if errors in the RFT – indicating more visual-dependent individuals – are associated with disorders where visual-vestibular conflict has been implicated: motion sickness,

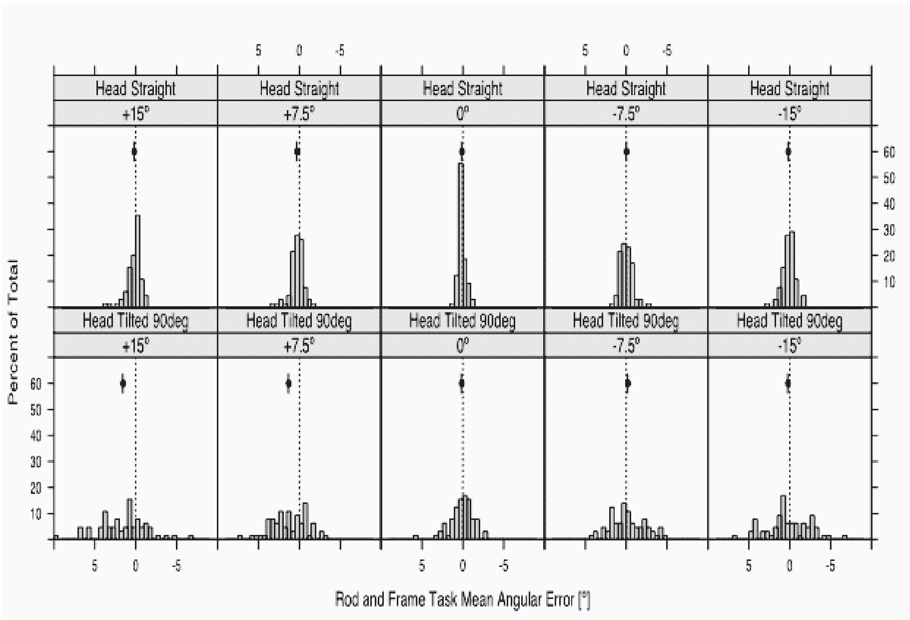

Fig. 2. Distribution of the participant's mean angular error in the Rod and Frame Test, shown for the condition where the participant's head was straight (top row) and the condition where the participant's head was tilted 90º to the left (bottom row). The angles listed, +15°, +7.5°, 0°, -7.5°, and 15° refer to the frame's tilt regarding the true vertical (see Methods). The vertical dotted line marks the zero degrees of angular error and the circle, and short line marks the sample's mean angular error (i.e., averaging across all participants)

Tab. 1. Mean angular error in the Rod and Frame Test. The confidence interval was computed using the method in Pewsey et al. (2013) p. 90

Frame Orientation	Head Straight		Head Tilted 90 degrees to the Left	
	M (SD)	95% CI	M (SD)	95% CI
+15º	0.186 (0.026)	[0.184, 0.188]	1.351 (0.065)	[1.346, 1.356]
+7.5º	0.271 (0.026)	[0.269, 0.273]	1.273 (0.053)	[1.269, 1.277]
0º	0.102 (0.018)	[0.101, 0.103]	0.139 (0.042)	[0.136, 0.142]
-7.5º	- 0.03 (0.026)	[-0.032,-0.028]	- 0.199 (0.055)	[-0.204,-0.195]
-15º	- 0.15 (0.026)	[0.148, 0.152]	- 0.197 (0.063)	[0.192, 0.202]

postural instability, and acrophobia. We computed the absolute value of the RFT's mean angular error for the condition of frame orientation at +15° and head tilted (the condition with the highest RFT error) and only considered this score in the following analysis; we examined the correlation between the RFT absolute mean angular error, the score in the Motion Sickness Susceptibility Questionnaire, the performance in the Sharpened Romberg Task, the score in the Acrophobia Questionnaire, and the score in the Albany Panic and Phobia Questionnaire. The three sub-scales of the Albany Panic and Phobia Questionnaire (social phobia, agoraphobia, and panic disorder) were included separately in the analysis. The Shapiro-Wilk normality test was applied to all measures in question. The null hypothesis that the variable followed a Normal distribution was rejected for a subset of the measures (all p-values < .001): the absolute mean angular error in the RFT; performance in the Sharpened Romberg Task; and the Panic sub-scale score. To measure association, we used a non-parametric test, Kendall's Tau-B for all pairwise comparisons; the results are in Table 2.

The correlation analysis revealed that the participant's scores on phobia-related measures were all associated, with a positive correlation coefficient: scores on the three subscales in the Albany Panic and Phobia Questionnaire were all correlated, a finding in line with studies that used this measure (see Brown, White, & Barlow, 2005); in addition, the same three sub-scales are all positively correlated with the Acrophobia Questionnaire measure. The phobia-related measures were also all positively correlated with the motion sickness score. We further examined the correlations between these five measures using a partial-correlation test, as implemented in the R package 'ppcor' (Kim, 2015). Partial correlation between the panic sub-scale score and acrophobia questionnaire score, when controlling for social phobia, agoraphobia, and motion sickness, was significant ($t_B = .25$, $p < .01$). The remaining significant partial correlations

Tab. 2. Kendall's Tau-B correlation coefficient between the scores, computed per participant, for: absolute mean angular error in the RFT; motion sickness; Romberg Test; acrophobia; social phobia sub-scale, agora phobia sub-scale, and panic sub-scale. Note: * p < .05; ** p < .01; *** p < .001. (1) This coefficient was computed only for participants with motion sickness scores greater than zero (N = 52)

	1	2	3	4	5	6	7
1. Absolute mean angular error in the RFT (Head Tilted; +15º Frame)	-						
2. Motion sickness Susceptibility Questionnaire	.23* (1)	-					
3. Sharpened Romberg Test	-.06	-.12	-				
4. Acrophobia Questionnaire	-.04	.19*	-.18*	-			
5. Social Phobia score–Albany Panic and Phobia Questionnaire	-.11	.27**	.13	.28**	-		
6. Agoraphobia score–Albany Panic and Phobia Questionnaire	-.02	.30***	-.02	.27**	.49***	-	
7. Panic score–Albany Panic and Phobia Questionnaire	-.05	.23*	-.07	.34***	.24**	.35***	-

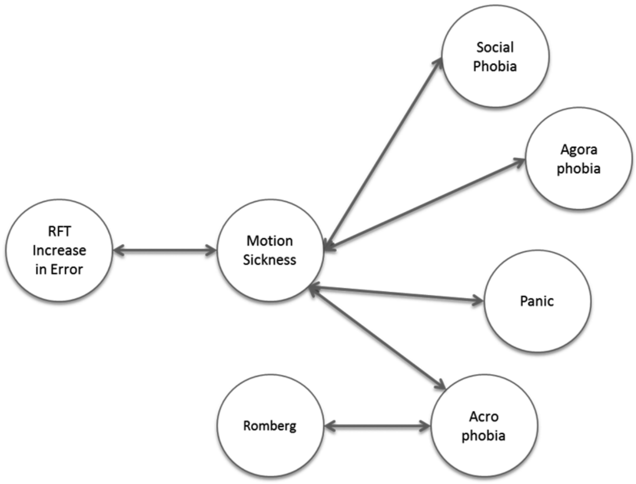

Fig. 3. Summary view of the key significant correlations from Table 2

are between the subscales of the Albany Panic and Phobia Questionnaire: social phobia subscale and agoraphobia subscale (partial t_B = .40, $p < .001$); agoraphobia subscale and panic subscale (partial t_B = .22, $p < .05$).

Regarding the Rod and Frame Test, the only disorder that was correlated with the absolute mean angular error in the RFT was motion sickness. The correlation coefficient was positive: higher scores in the Motion Sickness Susceptibility Questionnaire were associated with larger absolute mean error in the RFT, in the condition with the head tilted. The coefficient was marginally significant when considering the complete sample (t_B = .16, $p < .06$, N = 65) but was significant if we excluded participants with a score of zero in the Motion Sickness Susceptibility Questionnaire, (t_B = .23, $p < .02$, N = 52) – we report the coefficient for the restricted sample in Table 2.

Regarding the Romberg postural control task, it was also correlated with only one disorder, acrophobia, and the association was negative, (t_B = -.18, $p < .05$). Although acrophobia was correlated with motion sickness, (t_B = .19, $p < .05$), the correlation between the Romberg task and motion sickness was not significant (t_B = -.12, $p < .18$), including if we only consider participants with a zero score in the motion sickness measure, (t_B = -.14, $p < .16$, N = 52).

Finally, although panic disorder was correlated with motion sickness and acrophobia, we found no correlation with postural stability, the Romberg measure or the RFT.

DISCUSSION

In summary, (see Figure 3) the main findings in this study show a correlation between motion sickness (only) and the rod and frame test (RFT) and only when the participant's head is tilted. All other disorders show no correlation with this test. Regarding posturography, only acrophobia is correlated with the Romberg test. Overall, all disorders correlate between each other when observing the questionnaires only.

Regarding motion sickness (MS), a correlation between the rod and frame test and MS was previously hypothesized and studied (e.g., Barrett & Thornton, 1968; Kennedy, 1975; Long, Ambler & Guedry, 1975) with contradictory results. The previous studies did not manipulate the input for the vestibular system, and by doing so, this study seems to find the RFT to be a good method to evaluate MS. By tilting a participant's head, we were able to find results probably because at an upright posture the gravitational (vestibular) and the egocentric vertical (body) are aligned, whereas, in a tilted head or body position, the two coordinate systems are decoupled. Tilts of the head and body induce displacements in the subjective visual vertical (Luyat & Gentaz, 2002) and an increased subjective visual vertical error (relative to the gravitational vertical) towards the head orientation had been previously observed (Funk, Finke, Müller, Utz, & Kerkhoff, 2010; Witkin & Asch, 1948). These changes in participant's head orientation allowed one to observe and measure the vestibular influence and consequent gravitational input modulation in the visual task. This observation suggests that the integration windows (e.g., Di Luca, Machulla, & Ernst, 2009; Mahoney, Li, Oh-Park, Verghese, & Holtzer, 2011) of participants with motion sickness are more vulnerable to postural changes compared to controls. Perception of coherence between the visual and vestibular sensory modalities might be more biased in participants with motion sickness. As this window varies within a measurable amplitude window, future studies should approach this question anew. This can be a method to study cases of ambiguous stimulation, in which symptoms or disorders such as motion sickness (Balaban & Yates, 2004; Brandt et al., 2002) can result. Interestingly, participants with MS did not show higher postural instability compared to other participants. As such, the postural instability relationship to MS according to the Riccio and Stoffregen, (1991) and Stoffregen and Smart (1998) model might be independent of postural vulnerabilities (e.g., Warwick-Evans, Symons, Fitch, & Burrows, 1998) and deficient perceptual-motor responses might only manifest themselves under disorienting conditions (e.g., Owen, Leadbetter, & Yardley, 1998).

Only the specific environmental type phobia: acrophobia was again negatively correlated with a participant's performance on the Romberg Test. All other disorders did not show any association with postural stability; this finding was previously reported by others regarding acrophobia (e.g., Boffino et al., 2009; Coelho & Wallis, 2010) but had not previously been placed in comparison with other disorders.

All disorders correlate between each other when observing the questionnaires. The most important for this study was the correlation between acrophobia and panic since the other correlations (panic and agoraphobia and social phobia) are well known. A possible correlation between acrophobia and panic has been previously addressed by Davey et al. (1997). In a population of university students, Davey and colleagues reported that measures of acrophobia were highly associated with a tendency to interpret ambiguous bodily feelings as threatening. This characteristic was also found by Coelho and Wallis (2010), who used the same bodily feelings questionnaire, the body sensations questionnaire (BSQ) from Chambless et al. (1984), and found it to be associated with a fear of heights. Davey and colleagues argue that the observed comorbidity between acrophobia and agoraphobia can be linked to similar biases in the interpretation of bodily feelings. In this study Panic disorder differs from acrophobia because the former does not seem to correlate with neither the RFT nor the RT tests whereas acrophobia seems to have a clear postural influence.

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